

# Visualising Matter and Cosmologies: A Transhistorical Example\*

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## Abstract

We propose a connection between the visualisation of cosmic matter and structure formation in the Cartesian tradition and that used by contemporary astrophysics. More precisely, we identify cosmological simulations of large scale structure in the Universe with the system of vortices in Descartes physics. This connection operates at different levels of the images: their representational purpose; the theoretical systems behind their use; and, finally, their function and materiality as visual productions. A skilled use of image analysis is necessary to stress the continuities and peculiarities between different epochs and disciplines.

*La gran lección filosófica de la ciencia contemporánea consiste, precisamente, en habernos mostrado que las preguntas que la filosofía ha cesado de hacerse desde hace dos siglos las preguntas sobre el origen y el fin son las que de verdad cuentan (Paz 2009: 179).*

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In 1644, the Dutch artist and mathematician Frans van Schooten the Younger (1615-1660) visualised the system of vortices described by Descartes in his *Principia Philosophiæ* (Fig. 1). Almost 350 years later, the astrophysicists Melott and Shandarin published the results of their simulations to visualise large scale cosmological structure in The Astrophysical Journal (Fig. 2). These two images appear very similar, yet for a multitude of reasons they are radically different.

## Shattering motion and the Big Bang: Cosmos as history

Descartes configured the grounds of his physics in *Le Monde*, a text written between 1629 and 1633 but withheld from publication until 1664 due to Descartes anxiety about the persecution of Galileo. In *Le Monde*, Descartes expounds a theory explaining the formation of the cosmos, but not its origin, since it was assumed to be a creation of God. Descartes posits an already-created matter “that should be imagined as the hardest and solidest body existing in the world” (Descartes 1989 [1664]: 132). Once the initial conditions are set, he describes the dynamics of their evolution to explain the formation of the actual Universe. At a given moment, God started to shake this compressed matter in such a way that the shaken parts divided themselves, triggering the motion and subsequent division of the closest ones in a kind of “chain reaction”. As a result of this primordial shattering motion, the matter acquired the most diverse forms, “like pieces *exploding* when a stone is broken” (Descartes 1989 [1664]: 136).

Descartes model bears remarkable similarities to the contemporary observational framework of physical cosmology, in which the Universe is understood to have been more homogeneous, denser and hotter in the distant past than it is today. Like Descartes in *Le Monde*<sup>1</sup>, contemporary cosmological theories attempt to explain the *formation* of the modern cosmos from specific initial conditions without seeking their origin. Indeed, a standard theoretical picture of these origins is still lacking: processes concerning the

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<sup>1</sup>After the bad fortune of Galileos affaire, Descartes postponed the publication of *Le Monde* and stressed in his *Principia* the role of God in every process. However, when *Le Monde* was finally published, the first exposition of his theories was available consequently we can attest that the relevance of god was not at a first instance the most significant factor.

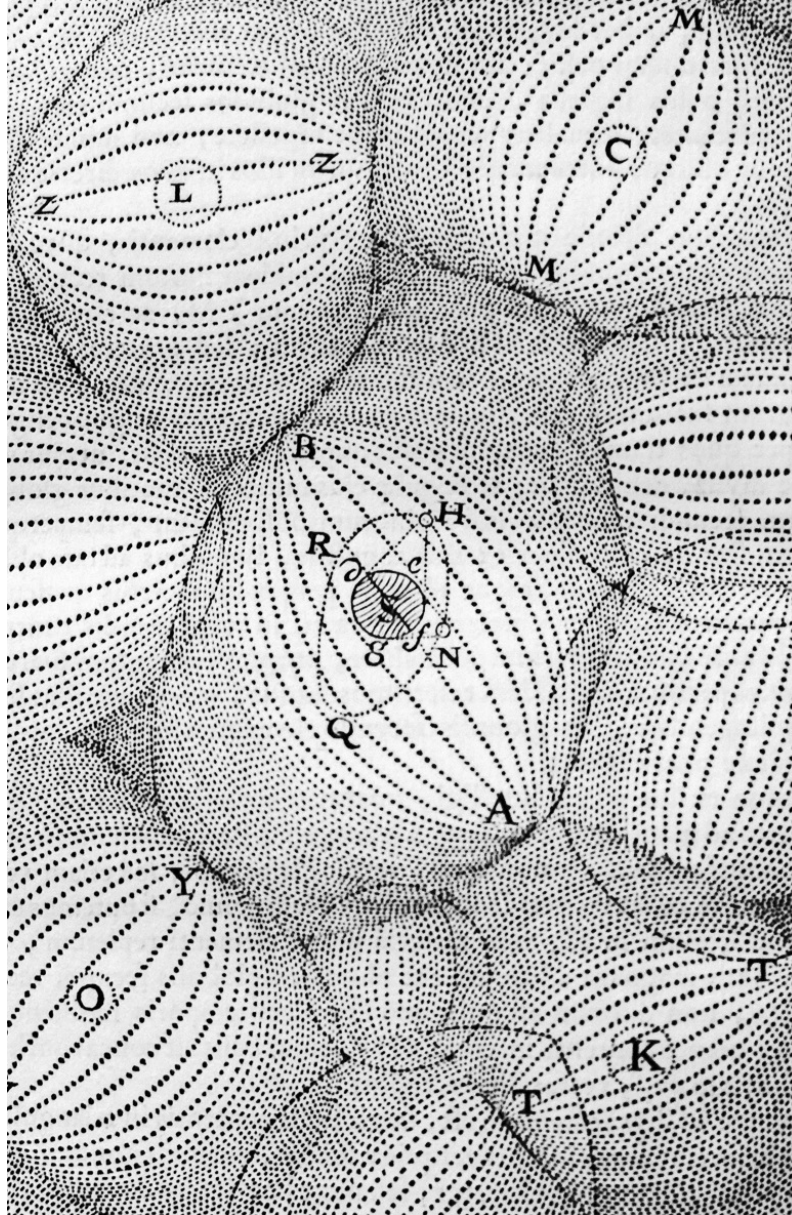


Figure 1: Frans van Schooten the Younger, woodcut, system of vortices in Descartes' *Principia Philosophiæ* (Amsterdam: Ludovicum Elzevirium, 1644). Image taken from the 1664 edition. © Staatsbibliothek zu Berlin Preußischer Kulturbesitz, Abteilung Historische Drucke.

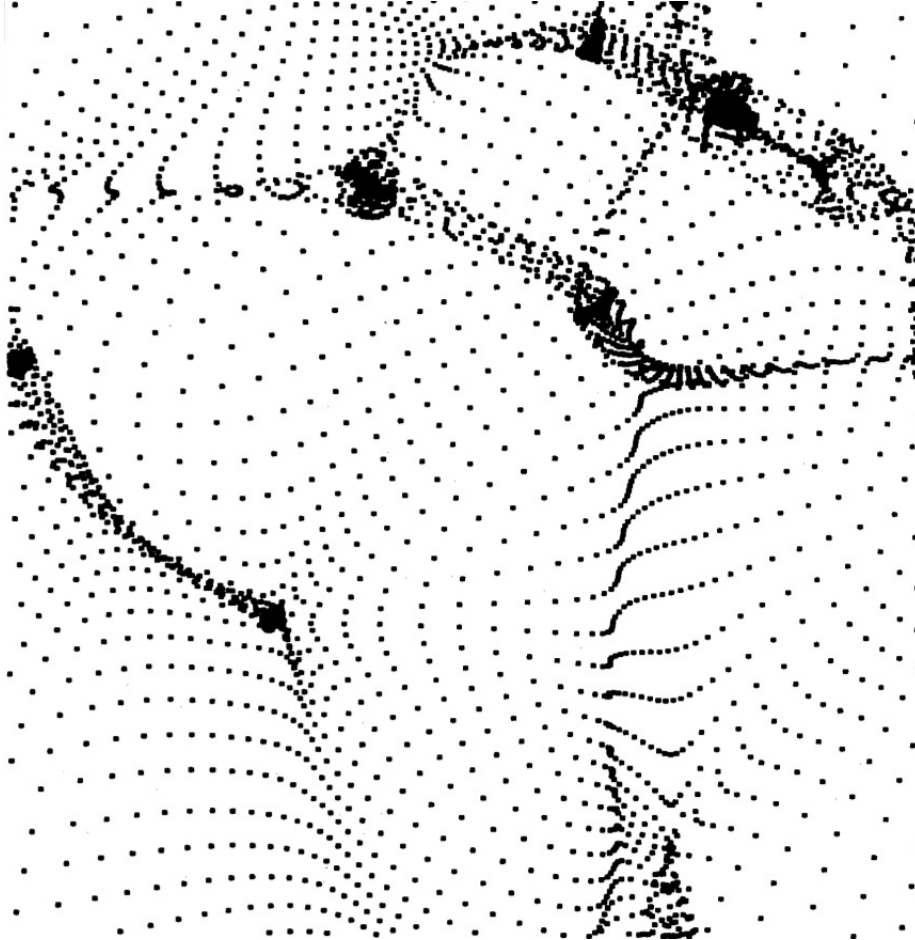


Figure 2: Adrian L. Melott and Sergei F. Shandarin, simulation of density perturbations in structure formation on cosmological scales, appeared first in “Gravitational Instability with High Resolution”, *The Astrophysical Journal* 343 (1989): 28. © Melott and Shandarin. Reproduction with the kind permission of the authors.

asymmetry between created matter and anti-matter, and the origin and nature of the initially small density inhomogeneities that constitute the seeds of present-day galaxies, for example, are explained by different schemes that await confirmation by future particle physics experiments.

## Fluid media: subtle matter and dark matter

In addition to these initial (exploding, expanding) conditions, it is useful to consider several aspects of the properties and implications of the conception of matter deployed by Cartesian and contemporary models, since these notions influence their understanding and explanation of structure formation. A dialogue exists between the Cartesian and contemporary models at the level of their visual components. Moreover, paying attention to the similarities and the differences of the theoretical frames underlying (and manifest through) these visualisations can be extremely productive.

Descartes uses the concept of subtle matter, a fluid composed of particles in constant motion. Van Schooten depicts its penetrable nature, subjected to constant change and interactions, by dotted surfaces (see fig. 1)<sup>2</sup>. From a historical perspective, one of the main contributions of his model was the introduction of the visualisation of matter as a key element in astronomical work. In doing so, special consideration was given to the *quality of matter as essence of the model*. When other authors popularized the Cartesian model, in most cases only this dotted surface was highlighted. The visualisation of cosmic matter and how it forms the general structure, started to be more important than concrete phenomena or mathematical laws. This became a distinctive visual feature of Cartesian physics, even in abstract figures. As a consequence, the traditional way of presenting astronomical diagrams (considering only orbital trajectories and the position/organisation of bodies) was enriched by the depiction of cosmic matter. An inspection of diagrams depicting the Tychonic and the Cartesian systems in a 1761 English translation of the *Conversations on the Plurality of Worlds* by Fontenelle provides an illuminating example<sup>3</sup> in addition to the concentric circles delineating the

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<sup>2</sup>For a comparable use of dotted surfaces, see Ayala, Lucía, “Surpassing human nature: Reinventions of and for the body as a consequence of astronomical experiments in the seventeenth and eighteenth centuries”, *Metaverse Creativity* 1: 1 (2010), specially pp. 109-110.

<sup>3</sup>First published in Paris: Veuve C. Blageart, 1686.

orbits, there are dots filling the gaps between them. But this is merely one example within a larger tradition. From 1664 onwards, it was not possible any more to construct an astronomical diagram without attracting attention to matter as one of its main elements, since matter was an essential factor in the formation of structures.

This logic of astronomical representation remains with us today. The first physically accurate representations of large-scale structure formation models, obtained through computational experiments, also highlight the role of matter visualisations. In scientific papers, the matter distribution is depicted with dots that represent computational, non-physical, particles. This discretization of matter into particles is necessary to perform the calculations, even when the physical model corresponds to a fluid. First implemented in supercomputer simulations in the 1970s, particle-based models remain a workhorse of computational astrophysics. However, the graphical representation of these models has evolved significantly, such that new visualisation software renders the simulation output and yields a closer graphical approximation of the postulated fluid nature of the matter being simulated. In the images from the Millennium Simulation performed by the Virgo Consortium at the Max Planck Institute for Astrophysics in 2005, dots spread out into different shades and hues, with colour palettes evocative of the imagined nature of dark matter. By comparing this kind of image with the versions in the seminal papers of the field, where the particles are clearly depicted as dots, it is evident that a higher degree of sophistication in the visual language has enabled the visualisation of more information. If the Millennium Simulation were represented by dots, all the nuances in the filaments, voids and knots would disappear, being reduced to a black smudge. Nevertheless, the basic topological information of the cosmic web would be contained in both cases.

While Cartesian physics is based on “subtle matter” composed of particles in motion, contemporary physical cosmology holds that the dominant matter component in our Universe is “dark matter”. However, dark matter is not immediately compatible with the current framework of particle physics. It emerges as a consequence of our conceptual understanding of gravitation: the equations describing its behaviour correspond to a collisionless fluid that only interacts through gravity. In other words, currently the behaviour of dark matter cannot be described from basic principles of particle physics (a dark matter particle has not been detected yet) and, therefore, the only available approach is through its gravitational effects. To fully explore these effects, numerical simulations are required.

## Structure formation: haloes and vortices

We have mentioned the differences between the renderings of the first large-scale structure simulations and the most recent ones. An important consequence of the increasingly sophisticated visual language used by this field of research has been the possibility to observe the emergence of new structures inside the cosmic web, namely high concentrations of dark matter with shapes close to spherical and having a spinning motion. These concentrations are called *haloes*, and they play a fundamental role in galaxy formation models.

In galaxy formation models, each galaxy is placed inside a dark matter halo that is gravitationally attracted to other haloes, which can therefore collide and merge. The galaxies inside the haloes can also fuse, transforming their morphology: a larger galaxy is formed out of two smaller ones. For example, the Milky Way and Andromeda, our closest disk galaxy companion, are expected to merge in five billion years. The resulting shape is expected to be spherical, instead of a disk, as the galactic structure changes during the merger. This is the basis of the hierarchical picture of galaxy formation, where structures grow from the merging of smaller ones, while their host dark matter haloes trace the cosmic web.

This modern chronicle once again resonates with Cartesian physics. According to Descartes model, matter is composed of particles in motion revolving around several centres. This behaviour forms different systems or vortices, each one described as “a heaven that spins round the star” (Descartes 1989 [1664]: 140). The vortices are also labelled as “large heavens”, being “very unequal in size” among each other (Descartes 1989 [1664]: 226). Since they are liquid, the shape of vortices is supposed to be oval (Descartes 1989 [1664]: 186). The heavenly bodies are placed in the middle of the vortex to which they belong. This interplay between heavenly bodies and vortices (or “large heavens”) recalls galaxies and haloes in contemporary physical cosmology.

Developing this point further, the dynamics of vortices also mirror the hierarchical merging of haloes. By definition, the Cartesian particles are constantly moving and they may collide, leading to erosion or fusion. In either case, this collision changes the structure of matter (Descartes 1989 [1664]: 146). Vortices disappear and their respective centres (the heavenly bodies) approach each other, forming new structures. Each satellite of Jupiter, for example, was considered by Descartes to be the remains of an ancient, more

complex system, whose original structure was lost due to a collision. When their respective contexts vanished, the satellites moved towards the nearest body (in this case the planet) and were integrated into the system, forming a new vortex. One of the engravings in the *Natural History* by Buffon, published in 1752, presents God creating the Solar System as a series of fluid vortices. Each planet is depicted as originally belonging to a separate structure, prior to the present-day organisation of their orbits around the Sun.

## Images and simulations shaping large-scale structures

Frans van Schooten was entrusted with the task of visualising the system of vortices theorised by Descartes; together, both Descartes and van Schooten gave *tourbillons* their shape. In 1989, Melott and Shandarin published a series of technical papers dealing with the simulation and visualisation of large-scale structure. This essay has suggested that a comparison between the two images can be undertaken on multiple levels, finding similarities at the representational level and between their respective theoretical frameworks. To complete this comparison, we will examine some aspects of the materiality of the images themselves.

Both models present a fragment as synecdoche of the whole: the systems cover the entire surface, extending themselves to the borders of it. In addition, the structure is composed of repetitive elements. These two aspects, *fragment and repetition*, visually indicate a wider space beyond that already shown. In other words, what we know about discrete areas of the Universe can be applied to the whole. Taking into account the limitations of the observations, this factor is quite relevant in order to achieve a general valid model. Superposed borders delimit the vortices and interconnect the systems through shared areas, stressing the penetrability of the fluid medium. Borders do not segregate individualities; instead, they highlight the fact of belonging to a complex system. In the second example, the visualised computational particles present filaments connecting large dark matter concentrations. Descartes emphasized a *cluster of vortices*, or penetrable, interconnected, and volumetric entities containing structures centred around stars, with orbiting planets and satellites; the contemporary model lays stress



on the emergence of a *cosmic web*, or a network of large dark matter filaments interconnecting the most massive galaxy clusters. For both models, voids are important. Descartes neglected the possibility of a vacuum, due to the fact that there are particles of matter everywhere in the cosmos. To make this aspect clear, the triangles originating in the interstices among the systems are covered with dense dotted surfaces. For the dark matter model, voids (the regions with a sparse particle distribution) are important as well from a quantitative and technical point of view.

The main divergence between each image lays in their function. On one hand, the vortices are a *visualisation of a theory*, a visual explanation containing the key ideas expounded by Descartes in the text. In this sense, the engraving is as abstract as the theoretical level itself. On the other hand, simulations of large-scale structure are a direct result of a concrete need to reproduce the available observations. They are an *indispensable tool to verify the theory*; the success of a model derives from what is revealed in the simulation. Figure 1 visualises Cartesian theory; Figure 2 visualises the numerical experiment that will shape the theory. For this reason, the images are radically different with respect to the contexts to which they belong.

The process of producing images has changed radically since the mid twentieth century. Contemporary scientists have constructed a new relationship to the images that they obtain, generate and analyse. In the specific context that we have discussed, the main improvements have been achieved through the introduction of simulations. Visually comparing the structures derived from a simulation and implied by observations plays a vital role in the work of contemporary astrophysicists; this process of visual inspection and recognition escorts the quantitative labor of extracting and comparing detailed statistics.

As images, Cartesian vortices and contemporary large-scale structure are quite different from a technical and functional point of view. But conceptually, again, they are quite similar. In *Le Monde*, Descartes presents the whole explanation of his system as a simulation:

For a short time, then, allow your thought to wander beyond this world to view another, wholly new one, which I shall cause to unfold before it in imaginary spaces. (Descartes 1989 [1664]: 99).

And my plan is not to set out (as they the philosophers do) the things that are in fact in the true world, but only to make up as I please from [this matter] a [world] in which there is nothing

that the densest minds are not capable of conceiving, and which nevertheless could be created exactly the way I have made it up. (Descartes 1989 [1664]: 107).

In order to conceive the new physics that he proposes, Descartes commences by establishing the conditions of a certain configuration of matter; he then applies the laws that he understands as valid and observes the results in this simulated world. He asserts that the same principles can be applied to the actual world. The validity of Descartes system lies in this comparison or analogy. The same method of shaping physical theories through simulations is also applied today.

## Conclusions

A comparable basic understanding of the composition and behaviour of the Universe can be traced from the Cartesian system of vortices to contemporary physical cosmology. Whether shaped by God or by the Big Bang, the hard/dense primordial matter started to evolve, forming new structures as consequence of its expansion. The constitution of cosmic matter particles in motion within a fluid medium is depicted by dotted surfaces in both cases, forming together a long tradition in modern science in which the visualisation of matter constitutes the basis of the model. Since Descartes, moreover, theories in physics require simulations to be both explained and shaped.

Our understanding of art history dealing with astronomy does not consist of presenting artistic projects inspired by this science. On the contrary, we focus our attention on astronomical productions themselves, that is to say, specific visual materials used by scientists to make science, whether they are produced by artists, as in the case of Descartes, or by scientists who create their own visualisations. In any case, what is important to stress here is the necessity of a deep understanding of the image as a crucial component of astronomy. One cannot underestimate its relevance by reducing it to a mere “representation” or “illustration”: scientific images are not illustrations, but *pivotal tools in the process of knowledge production*. The specific case of cosmic matter reveals the important role of visualisations. In the examples outlined above, matter is constructed directly *in and through the image*. Advanced techniques to see the cosmic particles were not at Descartes disposal; even today, we do not have a technique to detect dark matter particles directly. In both cases the visualisation of matter is required to make

the science evolve. Therefore, the examples we have shown are not representations, because the physical appearance of the subject to be supposedly “represented” was and is unknown; but they are the objective results of the knowledge we have attained. From this standpoint, an analysis from a renewed art historical perspective, when applied to science, provides an essential tool for understanding its materials with a new strategy.

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## References

Descartes, R., *Principia Philosophiæ* (Amsterdam: Ludovicum Elzevirium, 1644).

Descartes R., *Le Monde. Traité de la lumière / El Mundo. Tratado de la luz*, bilingual edition, trans. by Salvio Turr (Barcelona: Anthropos, 1989 [1664]).

Melott A. L. and Shandarin S. F., “Gravitational Instability with High Resolution”, *The Astrophysical Journal* 343 (1989): 26-30.

Paz O., “Rodeos hacia una conclusión”, in *La llama doble* (Barcelona: Seix Barral, 2009), 174-203.

Springel V., White S. D. M., Jenkins A., Frenk C. S., Yoshida N., Gao L., Navarro J., Thacker R., Croton D., Helly J., Peacock J. A., Cole S., Thomas P., Couchman H., Evrard A., Colberg J. and Pearce F., “Simulations of the formation, evolution and clustering of galaxies and quasars”, *Nature* 435 (2005): 629.